Utility Patent Application

of

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for

Optical Fiber Terminator Using Toroidal Reflective Surfaces

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority from copending US provisional application number 60/392,497 filed 06/27/02, which is hereby incorporated by reference.

FIELD OF INVENTION

The present invention relates generally to optical fiber terminators for out-coupling and guiding a light beam obtained from an optical fiber, more specifically, the invention relates to terminators employing toroidal reflective surfaces for guiding the out-coupled light beam.

BACKGROUND

A number of fiber terminals or light guiding tips are discussed in the prior art. Most of these employ gradient index (GRIN) lenses, ball lenses, C-lenses, microoptic aspheric lenses and microoptic spherical lenses for guiding

a light beam outcoupled from the optical fiber. For more details on various terminals and connectors which can be utilized with optical fibers and light sources the reader is referred to, e.g., U.S. Patents Nos. 4,068,121; 4,993,796; 5,479,543; 5,682,452; 6,086,263; 6,253,007.

Toroidal reflective surfaces are taught in the field of telescope optics. For more details of telescopes using toroidal reflectors the reader is referred to U.S. Pat. No. 3,961,179 and to James M. Spinhirne et al., "Adaptive Optics Using the 3.5 m Starfire Optical Range Telescope", SPIE, Vol. 3126, pp. 257-268. In fact, the prior art also teaches the use of toroidal reflective surfaces in laser beam condensing devices as documented in U.S. Pat. No. 5,889,626.

OBJECTS AND ADVANTAGES

The prior art teachings do not address stable fiber optic terminals with low chromatic aberration for use in broadband applications. In fact, what is needed are fiber optic terminals exhibiting no birefringence effects, no polarization mode dispersion as well as environmental stability and no appreciable long-term changes in optical properties. Such terminals should be rugged such that they can be employed for fiber termination in adverse environmental conditions, e.g., in environments experiencing large temperature and humidity fluctuations.

Accordingly, it would be desirable to provide an optical fiber terminal having the requisite properties that the prior art terminals lack. Specifically, such a terminator exhibits low aberration over a wide wavelength range and

its dimensions scale such that thermal expansion/contraction of the terminator body affects all dimensions commensurately and preserves long-term optical properties even in adverse environmental conditions.

These and other objects and advantages of the invention will become apparent upon further reading of the specification.

SUMMARY

In one embodiment of the invention, an apparatus is provided for terminating an optical fiber. In another embodiment, an apparatus is provided for manipulating light. The apparatus may include a body exhibiting a substantially uniform refractive index n_b, an input interface that allows light from the optical fiber into the body, a concave reflective surface within the body opposite the input interface that reflects the incoming light in a near-normal direction, a convex toroidal surface within the body positioned to reflect the reflected light in an off-normal direction, and an output surface for out-coupling the light beam. Preferably, in some embodiments, the azimuth angle between the near-normal and off-normal directions taken about a rotation axis connecting the respective points of incidence of the light beam on the concave and convex surfaces is less than 90 degrees. It is also preferred in some embodiments that the input interface be located adjacent the convex toroidal reflective surface. The input interface may also be a surface of the body itself.

In one embodiment, the apparatus may include one or more folding mirror surface(s) to reflect the light beam within the body. This mirror may be coated by a reflecting material or may comprise a light-conditioning element.

In another embodiment, the concave reflective surface is a concave toroidal reflective surface. Preferably, the concave toroidal reflective surface and the convex toroidal reflective surface are adjusted to mutually cancel wavefront distortions in the light beam. The convex and concave toroidal reflective surfaces may also be dimensioned to either collimate or focus the light beam.

It is preferred in some embodiments that the body is composed of a molding material exhibiting a substantially uniform coefficient of thermal expansion. This molding material can be an organic polymer or glass, but is not limited to these materials.

In one embodiment, a reflecting material on the surface of the body coats the concave reflective surface and the convex toroidal reflective surface. An optical monitor may be coupled to the body for the purpose of monitoring the intensity of the light beam. This monitor may also be coupled to either the concave reflective surface or the convex toroidal surface.

In another embodiment, the body may contain a light-conditioning element in order to condition the light beam. It is preferred in some embodiments that this element be a coating selected from the group consisting of wavelength-filtering coatings, anti-reflection coatings, and

polarization-altering coatings; or a type of grating, but is not restricted to these elements. It is also possible to include this light-conditioning element on a surface of the body in an additional embodiment.

It is also possible for a plurality of optical fiber terminators to form a monolithic fiber terminator array.

In another embodiment of the invention, a method is provided for receiving and guiding a light beam by providing an optical fiber terminator having a body exhibiting a substantially uniform refractive index n_b, admitting a light beam into the body via an input interface, providing a concave reflective surface within the body opposite of the input interface to receive and reflect the light beam along a near-normal direction, including a convex toroidal reflective surface within the body for receiving the reflected light beam and reflecting the light beam along an off-normal direction, and out-coupling the light beam via an output surface of the body.

BRIEF DESCRIPTION OF THE FIGURES

Fig. 1 is a diagram illustrating a particular configuration of an apparatus according to one embodiment of the invention wherein an optical fiber is terminated with a focused or collimated beam.

Fig. 2 is a diagram illustrating an alternate embodiment of the invention incorporating a folding mirror for a more convenient geometrical arrangement.

Fig. 3 shows a mechanical design of an optical fiber terminating apparatus according to an embodiment of the invention.

Fig. 4A-C illustrates three possible array arrangements of optical fiber terminators according to several embodiments of the invention.

DETAILED DESCRIPTION

In accordance with one embodiment of the invention, as shown in Fig. 1, an optical fiber terminator **10** has a body **12** exhibiting a substantially uniform refractive index n_b. Body **12** has an input interface **14** for admitting a light beam **16** from an optical fiber **18** into body **12**. Body **12** is provided with a concave reflective surface **20** opposite input interface **14** and oriented to receive light beam **16** and reflect it along a near-normal direction A. Specifically, near-normal direction A is within an angle α from a normal N. Typically, angle α is in the range of a few degrees, e.g., 3°.

Body **12** is also provided with a convex toroidal reflective surface **22** positioned to receive light beam **16** reflected from concave reflective surface **20**. Surface **22** is oriented to reflect light beam **16** along an off-normal direction B. Specifically, off-normal direction B is at an angle β from the normal N. Typically, angle β is in the range of about 90°.

Body **12** has an output surface **24** through which light beam **16** is out-coupled. Output surface **24** may be a simple surface or it may be provided with coatings or other optical elements.

In one embodiment, body **12** of terminator **10** is fabricated such that an azimuth angle θ between near-normal direction A

and off-normal direction B taken about a rotation axis that connects the point of incidence of light beam **16** on concave surface **20** to the point of incidence of light beam **16** on convex toroidal surface **22** is less than 90°. Furthermore, input interface **14** is located adjacent convex toroidal surface **22** such that light beam **16** is in-coupled into body **12** right next to surface **22**. This geometry is convenient, as it reduces the overall dimensions of terminator **10** and provides for advantageous arrangement of surfaces **20** and **22** with respect to one another.

Body **12** may be made of a suitable material that has a substantially uniform refractive index n_b. In one embodiment the material is a molding material with a substantially uniform coefficient of thermal expansion (CTE). Such material includes, e.g., organic polymers as well as glass.

In some embodiments, concave reflective surface **20** may be a concave toroidal reflective surface. Whether toroidal or not, convex and concave surfaces **20, 22** may be adjusted to mutually cancel wavefront distortions in beam **16.** The curvatures of surfaces **20, 22** can be dimensioned to collimate or focus light beam **16**, depending on desired application.

To obtain good quality reflectivity of surfaces **20, 22** it is preferable to coat them with a reflective material. Such reflective material can be coated on the surface of body **12**. Specific reflective materials suitable for use with the wavelength range contained in light beam **16** may be determined by those skilled in the art.

Additional light-conditioning elements may be integrated into body **12** to condition beam **16**. For example, body **12** may be provided with coatings at input interface **14**, surfaces **20**, **22**, any folding mirror surface(s) and/or output surface **24**. The coatings may include various types of surface coatings including wavelength-filtering coatings, anti-reflection coatings and polarization-altering coatings. In fact, gratings for wavelength separation and other light-conditioning elements may be provided on body **12**.

Terminator **10** may have one or more folding mirror surface for reflecting light beam **16** within body **12**. Folding mirror surface(s) may be used to design the optical path of beam **16** as required in any specific application. Fig. 2 illustrates an optical fiber terminator **26** incorporating a folding mirror surface **28**.

In one embodiment, optical fiber terminator **26** operates almost identically to optical fiber terminator **10**. Light beam **16** is admitted through input interface **14** on a surface of body **12**. Concave reflective surface **20** is positioned opposite input interface **14** and oriented to receive light beam **16** and reflect it along a near-normal direction towards convex toroidal reflective surface **22**. Surface **22** is positioned to reflect light beam **16** along an off-normal direction. In this embodiment, instead of light beam **16** exiting body **12** through output surface **24**, it is redirected by folding mirror **28** and exits through an output surface **30** located on the surface of body **12** opposite input interface **14**. In this embodiment, the various elements may have

similar properties as those used in the apparatus described in Fig. 1. Alternatively, other arrangements could be achieved where one or more mirror surface is employed to redirect the light beam in a direction that is convenient for the apparatus to achieve the desired result.

In either of the above two embodiments, an optical monitor in the form of a photodiode may be coupled to body **12** for monitoring the intensity of light beam **16**. The photodiode can be coupled to any surface at which light beam **16** is reflected, e.g., one of surfaces **20**, **22** or the surface(s) of any folding mirrors **28**. Conveniently, a small aperture in the reflective surface, e.g., in the reflective coating, is made to allow sufficient light to strike the photodiode.

Fig. 3 provides an outer schematic of optical fiber terminator **26**. Note the sample dimensions provided for the device.

In Fig. 4A, a two-dimensional array **32** of optical fiber terminators **26** is shown wherein optical fiber terminators **26** are oriented in a horizontal row. Fig. 4B shows a three-dimensional array **34** of optical fiber terminators **26** wherein upright rows of optical fiber terminators **26** are stacked on top of each other. Lastly, Fig. 4C illustrates an inverted array **36** of optical fiber terminators **26**. An upside down row of optical fiber terminators **26** is stacked atop of an upright row of optical fiber terminators **26**.

The arrays illustrated in Figs. 4A-C illustrate just three possible arrays configured from optical fiber terminators **26**. Many other arrays/geometric configurations could be

imagined incorporating this and/or other type(s) of optical fiber terminators.